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Insomnia and sleep misperception

Insomnie et mésestimation du sommeil

C.H. Bastien [a,*,b], T. Ceklic [a,b], P. St-Hilaire [a,b], F. Desmarais [a,c], A.D. Pérusse [a,b], J. Lefrançois [a,b], M. Pedneault-Drolet [a,b]

[a] *École de psychologie, université Laval, pavillon Félix-Antoine-Savard, bureau 1012, 2325, rue des Bibliothèques, G1V 0A6 Québec, Canada*
[b] *Laboratoire de neurosciences comportementales humaines, centre de recherche, institut universitaire en santé mentale de Québec, 2601, chemin de la Canardière, G1J 2G3 Québec, Québec, Canada*
[c] *École de service social, université Sherbrooke, 2500, boulevard de l'Université, J1K 2R1 Sherbrooke, Québec, Canada*

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ABSTRACT

Sleep misperception is often observed in insomnia individuals (INS). The extent of misperception varies between different types of INS. The following paper comprised sections which will be aimed at studying the sleep EEG and compares it to subjective reports of sleep in individuals suffering from either psychophysiological insomnia or paradoxical insomnia and good sleeper controls. The EEG can be studied without any intervention (thus using the raw data) via either PSG or fine quantitative EEG analyses (power spectral analysis [PSA]), identifying EEG patterns as in the case of cyclic alternating patterns (CAPs) or by decorticating the EEG while scoring the different transient or phasic events (K-Complexes or sleep spindles). One can also act on the on-going EEG by delivering stimuli so to study their impact on cortical measures as in the case of event-related potential studies (ERPs). From the paucity of studies available using these different techniques, a general conclusion can be reached: sleep misperception is not an easy phenomenon to quantify and its clinical value is not well recognized. Still, while none of the techniques or EEG measures defined in the paper is available and/or recommended to diagnose insomnia, ERPs might be the most indicated technique to study hyperarousal and sleep quality in different types of INS. More research shall also be dedicated to EEG patterns and transient phasic events as these EEG scoring techniques can offer a unique insight of sleep misperception.

Mots clés :
Sommeil
Mésestimation
Insomnie paradoxale
Insomnie psychophysiologique
ERP
PSA
EEG
CAP
Complexe-K
Fuseau

RÉSUMÉ

La mésestimation du sommeil est souvent observée chez les individus souffrant d'insomnie (INS). Cependant, l'ampleur de cette mésestimation varie entre les types d'INS. Cet article est composé de sections dédiées à l'étude de l'EEG et sa comparaison avec les rapports subjectifs de sommeil d'individus souffrant soit d'insomnie psychophysiologique ou paradoxale et bons dormeurs. L'EEG peut être étudié soit sans intervention (en utilisant les données brutes) comme dans le cas de la polysomnographie ou l'analyse spectrale, soit en identifiant des patrons d'activation comme pour les patrons cycliques alternants (*cyclic alternating pattern*) ou encore en décortiquant l'EEG en évènements phasiques ou transitoires (complexes-K et fuseaux de sommeil). On peut également agir sur l'EEG en délivrant des sons et en étudiant leur impact sur les ondes de l'EEG comme dans le cas des potentiels évoqués, et surtout ceux cognitifs. Du peu d'études disponibles utilisant ces différentes techniques/mesures, une conclusion générale peut tout de même être tirée : la mésestimation du sommeil n'est pas facilement quantifiable et sa valeur clinique n'est pas adéquatement reconnue. Alors qu'aucune des techniques/mesures définies ici n'est disponible ou recommandée afin de diagnostiquer l'insomnie, la technique utilisant les potentiels évoqués cognitifs semble la plus appropriée ou juste afin de mesurer l'hypervigilance corticale

* Corresponding author.
E-mail address: celyne.bastien@psy.ulaval.ca (C.H. Bastien).

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(*hyperarousal*) et la qualité du sommeil chez les différents types d'individus souffrant d'insomnie. Finalement, plus de recherches devraient être dédiées à l'étude des patrons EEG et des évènements phasiques du sommeil puisque ces techniques apportent une compréhension différemment unique de la mésestimation du sommeil.

1. Abbreviations

CAPs	Cyclic alternating patterns
DSM-5	Diagnostic and Statistical Manual of Mental Disorders – Version 5
EEG	Electroencephalogram or electroencephalography
EKC	Evoked K-Complex
EOG	Electrooculography
EMG	Electromyography
ERPs	Event-related potentials
FFT	Fast Fourier Transformations
fMRI	functional Magnetic Resonance Imagery (MRI)
GS	Good sleepers
ICSD	International Classification of Sleep Disorders
INS	Individuals suffering from insomnia
KC	K-Complex
NCAP	Non-CAP
NREM	Non-rapid eye movement
N1	Negative wave appearing about 100 milliseconds after stimulus onset
N350	Negative wave appearing about 350 milliseconds after stimulus onset
PARA-I	Paradoxical insomnia sufferers
PSA	Power spectral analysis
PSG	Polysomnography
PSY-I	Psychophysiological insomnia sufferers
P2	Positive wave appearing about 200 milliseconds after stimulus onset
P3	Positive wave appearing about 300 milliseconds after stimulus onset
REM	Rapid eye movement
SE	Sleep efficiency
SKC	Spontaneous K-Complex
SOL	Sleep onset-latency
SWS	Slow wave sleep
S2	Stage 2 sleep
TST	Total sleep time
WASO	Wake after sleep onset

2. Introduction

Insomnia is among the most common health complaints in medical practice. Approximately 30% of the general population experiences some insomnia symptoms occasionally and 10% suffer from chronic and persistent insomnia [1,2]. Frequently reported consequences related to insomnia include fatigue, sleepiness, mood disruption [3], impaired attention and memory deficits [4], consequences being infrequently objectively confirmed [5].

3. Definition and types of insomnia

An insomnia disorder is defined as a complaint of prolonged sleep latency (labeled "sleep-onset insomnia"), difficulties in maintaining sleep (labeled "sleep-maintenance insomnia"), waking up too early in the morning (labeled "terminal insomnia"), and a mix of different sleep complaints (labeled "mixed insomnia"). In addition, the DSM-5 [6] specifies that to be considered a disorder, insomnia or its perceived consequences cause clinically marked distress or significant impairment of occupational or social functioning. Although insomnia can be acute, the current definition of insomnia specifies that it must be present for at least three months.

While the International Classification of Sleep Disorders (ICSD) [7] was previously distinguishing among different types of insomnia (Box 1), its new revised version [8] does not recommend a sub-classification of different types for clinical purposes as it mainly argues that empirical evidence is lacking to retain them. As researchers though, it is still strongly believed that at least two types of chronic insomnia (insomnia presenting itself without any other comorbid disorder) warrant attention as they are the most prevalent insomnia types and puzzling [9] and have seemingly different underlying pathophysiology [10–14]. As such, research shall still devote time to their study. These two types are psychophysiological and paradoxical (or sleep-state misperception) insomnia. In some cases, complaints of sleep difficulties are objectively observable, in other cases, they are not. Thus, a patient may either complain of sleep difficulties while objective polysomnographic recordings appear normal, or there may be constant and important gap between objective and subjective measures (for example, polysomnography [PSG] vs sleep diaries) of sleep [9]. As much as 50% of individuals suffering from insomnia could be poor estimators (displaying gross misperception) and classified as paradoxical insomnia sufferers [10,11,15]. While paradoxical INS (PARA-I) and good sleepers (GS) display similar results on measures of sleep macroarchitecture (for example the observed percentage in different sleep stages), there may be subtle differences in their microarchitecture [12]. On the other hand, typically, INS accurately estimating their sleep are those suffering from psychophysiological insomnia (PSY-I). Finally, these two types of INS are not mutually exclusive. Thus, an individual can show objective sleep-onset, sleep-maintenance or mixed objective sleep difficulties once his/her sleep has been recorded in the sleep laboratory but also present important discrepancies between his/her reports and laboratory sleep observations. As such, an individual might be complaining of mixed sleep difficulties over a long period of time, without showing any signs of depression or anxiety and at the same time, be of the paradoxical type [15]. Unfortunately, it is difficult to estimate the percentage of those

Box 1. Types of insomnia according to the ICSD.

Psychophysiological insomnia
Paradoxal insomnia
Idiopathic insomnia
Inadequate sleep hygiene
Behavioral insomnia of childhood
Insomnia due to (another) mental disorder
Insomnia due to (a) medical condition
Insomnia due to drug or substance

individuals presenting objective sleep difficulties in addition of gross misperception and, as suggested by St-Jean and Bastien [15], INS sleep difficulties (both objective and subjective) might be better found as distributed along a sleep difficulties 'continuum'.

This paper will introduce and discuss recent experimental research focusing on INS, with a special emphasis on paradoxical insomnia and/or the misperception of sleep. It will first briefly describe PSG results pertaining to INS compared to GS and then provide an overview of the neurophysiological research done in our laboratory and others. This will be achieved by using rigorous criteria so to obtain an homogeneous classification of types of insomnia as is done in our laboratory (see [16]) instead of those suggested by Edinger et al. [9], which are generally non-specific. For example, instead of the liberal sleep-state misperception or paradoxical terms, often only referring to a gross misperception of sleep, PARA-I, in addition of corresponding to the criteria for pure insomnia, will be defined as having:

- an objective total sleep time (TST) of more than 6 h 30 min and a sleep efficiency greater than 85% on nocturnal PSG;
- showing marked discrepancies between subjective and objective sleep measures (i.e. a difference of 60 min or more for TST, or a difference of at least 15% between subjective and objective measures of sleep efficiency).

The following observation is also common: complaint of severe sleep difficulties most of the time (sleepless nights on sleep diaries being an indicator of severe sleep difficulties). The different criteria presented here for paradoxical insomnia are based on a combination of our research experience (and of what others have also suggested previously – see [10] and [12] for example) and an extension of those suggested by Edinger et al. [9] and Feige et al. [13]. Comparisons with GS, those individuals satisfy with their sleep and not having subjective complaints of sleep difficulties while reporting a sleep efficiency of 85% or more in sleep diaries, and psychophysiological insomnia sufferers (PSY-I), criteria corresponding to those set forward by Edinger et al. [9], are used in our laboratory in order to capture the true essence of sleep misperception. It is our aim to show that important sleep misperception is linked to increased cortical arousal and that PARA-I shall display increased cognitive and electroencephalographic (EEG) arousal compared to PSY-I.

The following sections will be aimed at studying the sleep EEG and often comparing it to the subjective reports of sleep of individuals. Also, as is presented below, the EEG can be studied without any intervention (thus just by using the raw data) via either PSG or fine quantitative EEG analyses (power spectral analysis [PSA]), searching for EEG patterns as in the case of cyclic alternating patterns (CAPs) or by decorticating the EEG while scoring the different transient or phasic events such as K-Complex or sleep spindles. On the other hand, one can also act on the ongoing EEG by delivering stimuli so to study the impact on those on cortical measures as in the case of event-related potentials (ERPs) studies. Although these techniques or the study of phasic events in sleep and in insomnia are not usually used in clinical settings or for diagnostic purposes, they still are very helpful in characterizing the pathophysiology of the disorder. Once the pathophysiology of a disorder is well circumscribed or at least, better understood, it is then easier to design effective treatments or even prevent the appearance of the disorder. Thus clinical considerations will not be explored here, only research ones. However, before detailing every technique, the basis and the definition of insomnia in research is presented with the subjective ratings of sleep. We will then introduce each technique which will begin with a brief definition and then move to the different studies related to sleep and to its misperception in insomnia, when available. Finally, each section reaches a conclusion on presented results.

4. Sleep diary

A detailed clinical history/assessment of the patient's subjective complaint will significantly benefit complementary data from more systematic sources such neurophysiological and neuropsychological assessments. Sleep diary monitoring is an exceptional tool to document the perceived severity of insomnia. A sleep diary commonly requires self-recording of bedtime and arising time, along with morning estimates of sleep-onset latency, number and duration of awakenings, total sleep time, and several indices of sleep quality for the previous night. Even though they do not reflect absolute values obtained from polysomnography (see Appendix A), daily morning estimates of sleep parameters such as sleep-onset latency or wake after sleep-onset yield a reliable and valid index of insomnia [17]. A sleep diary also captures the night-to-night variability that often characterizes the sleep of chronic INS [18–20] compared to one or two nights of polysomnography. Of course, for paradoxical insomnia individuals, sleep diaries are often characterized by sleep disturbances on each and every night and good nights are very rare. In addition, we have previously shown that sleepless nights are often reported by PARA-I [21]. A sleep efficiency (total sleep time divided by time in bed) lower than 85% also characterizes INS. Based on the diary measures, sleep-onset (SOL) insomnia was typically defined by a latency to sleep-onset of at least 30 minutes, and sleep-maintenance insomnia was defined by time awake after sleep-onset (WASO) of at least 30 minutes. With the introduction of the DSM-5 and the ISCD-III, the reported sleep disturbance, either for SOL or for WASO, can be as low as of 20 minutes. On the other hand, early morning awakening can be operationalized by a complaint of waking up earlier than desired, with an inability to go back to sleep, and before total sleep time reaches 6.5 h. These criteria, while seemingly arbitrary, are useful to operationalize the definition of insomnia.

5. Polysomnography (PSG)

Insomnia protocols are usually conducted on two or three consecutive nights of PSG recordings. Usual PSG recordings include electroencephalography (EEG), electrooculography (EOG) and electromyography (EMG). PSG has two main objectives:

- codify the different NREM sleep (stages 1, 2, 3 and 4) and REM sleep (Fig. 1);
- screen for sleep disorders and quantify their respective severities.

One important limitation of PSG is that it does not provide a valid sample of an individual's typical sleep, and especially for INS. Actually, the sleep of GS is more disrupted during their first night of recording in the sleep laboratory (i.e., first night effect: worst sleep efficiency on the first night compared to subsequent ones), while the sleep of INS may actually improve (i.e., reverse first night effect: better sleep efficiency on the first night than on subsequent ones) [22]. Still, PSG is particularly helpful for studying types of insomnia, for example when studying PARA-I, since, by definition, it entails large discrepancies between objective and subjective estimates of sleep. Our own research group has suggested that paradoxical insomnia is best identified after large subjective-objective discrepancies have been observed on at least two out of four consecutive recording nights in the laboratory [16]. In any case, modest PSG differences are generally observed between INS and GS, INS tending to spend more time in stage 1, less time in

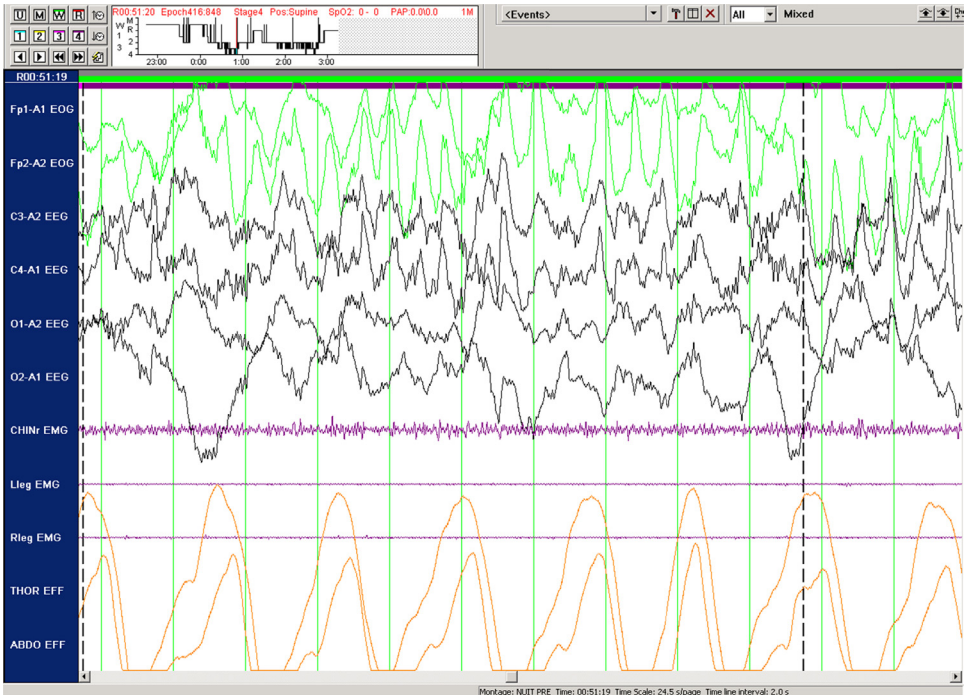

Fig. 1. Signals (channels) recorded from the participant displayed in this figures are those often used for scoring of sleep stages. Fp1 and Fp2 correspond respectively to left and right eye of electromyographic recordings (EOG). Subsequent channels include EEG leads (C3, C4, O1 and O2), EMG activity from the right chin (EMGr), left and right tibialis for leg movements (Lleg and Rleg), thoracic and abdominal bands for respiratory efforts. Tibialis and respiratory efforts are used to respectively obtain indexes for PLMS and apneoa/hypopnoea. The sleeping individual is presently in stage 4 sleep (eye movements following the EEG, high amplitude EEG – SWS and delta – and decreased EMG). In the white box, at the top of the figure, the all night hypnogram is displayed.

stages 3–4, and show more frequent stage shifts through the night [17,23,24]. During the day, our group has recently provided empirical evidence that both PSY-I and PARA-I differ on PSG measures from GS during napping [25]. These results are encouraging and do suggest that insomnia is a 24-hour problem and dividing INS in types might be quite informative about cortical processes at play. Nonetheless, because of limited between group differences observed so far between INS and GS on objective measures of sleep, it is very much suggested to use finer EEG or quantitative techniques to uncover cortical differences between INS and GS and also between PSY-I and PARA-I. Even if PSG has been considered the gold standard for a long time, it is usually unavailable on a day-to-day basis and for clinical diagnosis. In addition, because of contradictory results between labs for INS (all types combined) and GS in PSG recordings, PSG is recommended only in insomnia research and not in clinical settings, unless, of course, another sleep disorders is suspected. In addition, since information provided through PSG is limited, other finer cortical measures are needed to disentangle between subjective and objective insomnia and 'quantify' sleep misperception. One of these techniques is the study of cognitive information processing with event-related potentials (ERPs; Fig. 2).

6. Event-related potentials (ERPs)

An external physical stimulus or internal psychological event elicits small amplitude changes in the EEG, therefore providing a means to "probe" the extent of information processing within the nervous system during wake and sleep. Contrary to neuroimaging, which has an excellent spatial resolution, event-related potentials (ERPs) have a high temporal resolution (about one tenth of a millisecond). ERP components are classified according to their latencies: early components (<80 ms approximately) reflect sensory processing, those around 100 ms are linked to arousal and attention, and later components usually reflect higher order central nervous system processing related to cognitive functions [26]. The valence and latency of peaks are used to label the different components: "N" refers to a negative wave and "P" to a positive wave. Thus, for example, "N100" would refer to a negative wave appearing 100 ms after stimulus onset (note that ERPs are usually termed as N1, P2, P3 even though their respective latency is 100, 200 and 300 ms). A cognitive process (or role) is associated with most ERP, common processes being attention (N1), inhibition

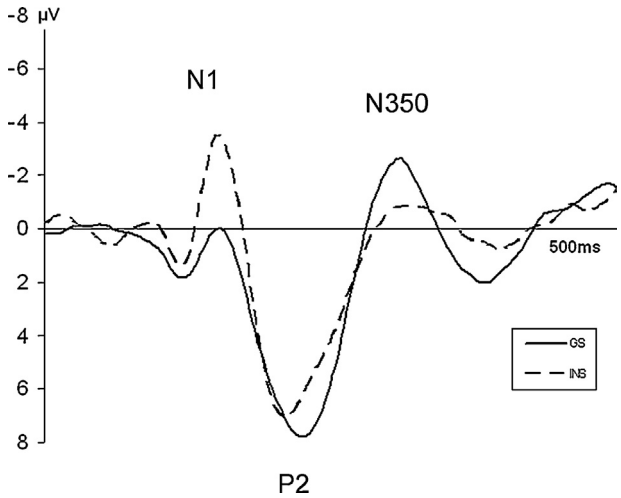

Fig. 2. Event-related recordings (ERPs). N1 represent a negative peak appearing about 100 ms after stimulus onset, P2, a positive peak appearing about 200 ms after stimulus onset and N350, a negative peak appearing about 300 ms after stimulus onset. N1 has been associated to vigilance while P2 has been associated to inhibition. N350 represent sleepiness. In the current picture, higher N1 amplitude in insomnia sufferers reflects hyperactivation/hyperarousal compared to good sleepers.

(P2), classification/categorization of an event (P3) and sleepiness (N350).

Although reduced relative to wakefulness, information processing still remains present during sleep. Usually, as an individual falls asleep, attention/vigilance processes decrease (thus N1 amplitude is lower from wake to sleep) and the inhibition of external stimuli is imperious to promote sleep (thus the amplitude of P2 gets greater and N350 appears at sleep-onset as a sign of the individual falling asleep). ERPs offer a means for direct evaluation of cortical activation time-locked to an experimental stimulus during wake and sleep. The auditory oddball paradigm (a train of stimuli containing a frequent standard tone and a deviant tone which occurs rarely) is often used to measure cortical excitability. Participants can be instructed to pay attention to the auditory stimulation (target stimuli generating a "P3") or they can be asked to simply ignore or not to pay attention to the stimulation (recordings of N1 and P2 during wake and N1, P2 and N350 during sleep-onset and sleep; Fig. 2).

According to the neurocognitive model and hyperarousal theory of insomnia [27,28], INS should show signs of enhanced sensory and information processing during wake and sleep. In ERPs words, INS should show more attentiveness and more inhibition deficits than GS. As such, general hypotheses might be as follows:

- INS should display a larger N1 (thus greater amplitude) and a smaller P2 (thus lower amplitude) to standard and deviant stimuli as well as larger P3 (thus greater amplitude) to target stimuli relative to GS;
- if INS have difficulties inhibiting cortical arousal, a smaller N350 (thus lower amplitude) will be observed at sleep-onset in these individuals relative to GS;
- if PARA-I are more hyperaroused than PSY-I, then impairments shall even be greater in the former group than the latter.

In 1993, Hull [29] showed that N350 was smaller in INS than in GS in the very early part of stage 2 sleep. Greater P300 amplitude immediately before sleep-onset and shorter response latency in INS relative to GS during wakefulness was also observed in this study. Those results suggested a hyperarousal state in INS compared to GS. Also in 1993, Regestein et al. [30] reported a significantly larger P1-N1 in INS compared to GS during wakefulness. Loewy et al. [31,32] also recorded a larger N1 and a smaller P2 in INS relative to GS during wakefulness. Our group [33] compared PSY-I and GS on N1, P2 and N350 components in a multi-assessment protocol. Hyperarousal upon awakening in the morning (greater N1 amplitude) in psychophysiological INS compared to GS was reported. In addition, a smaller N350 in INS than in GS was observed at sleep-onset. Altogether, these studies suggested that INS are more vigilant (or "aroused") during wakefulness than GS controls. In addition, at sleep-onset, studies also tended to show that inhibition deficits were present in INS.

Is sleep misperception linked to arousal and if so, will it be reflected through ERPs responses in PARA-I compared to those of PSY-I and GS? In some preliminary data, Bastien [34] showed that compared with PSY-I and GS, PARA-I presented larger N1 and P2 as well as lower N350 in the evening and at sleep-onset. Thus it seems that cortical arousal and inhibition deficits are underlying neurophysiological mechanisms of INS during wake and that these processes are more pronounced in PARA-I than in PSY-I and GS. The next question was: does hyperarousal persists during sleep between types of INS? It does seem like it. Recently, our group showed that N1 amplitude was generally larger in both INS groups compared to GS, and P2 amplitude was larger in PARA-I than in the two other groups, especially in rapid eye movement (REM) sleep. Results suggested that inhibition deficits were more likely to be present in PARA-I compared to PSY-I as PARA-I have to deploy more energy to disregard irrelevant stimuli [35]. In the same study, relationships between the degree of mismatch between subjective and objective sleep measures and the amplitude of N1 and P2 did not reveal that ERPs components varied much according to group belonging. Links between misperception and ERPs measures were observed only for PARA-I, with an overestimation in wake after sleep-onset (WASO) associated with increased N1 amplitude during REM and an underestimation of TST associated with higher N1 amplitude. Since larger N1 amplitude in REM is linked to the misperception of wake time during the night in PARA-I, and because PARA-I are more prone to be disturbed by auditory stimulation than PSY-I and GS [35], our group [36] suggested that an increased N1 in PARA-I may be a direct reflection of the obtrusiveness of stimulation and that this obtrusiveness may translate into a perception of "being more awake" for PARA-I, especially in REM sleep.

Because sleep quality variability is also quite challenging in insomnia [37], it is possible that information processing varies according to the quality of the night (preceding or following ERPs recordings). Some studies have thus tried to associate sleep quality in insomnia (subjective – diary and/or objective – PSG) to daytime measures of ERPs. Devoto et al. [38] compared INS and GS after a subjective "good night" sleep and after a subjective "bad night". They observed that P3 amplitude was lower after a good night in INS compared to GS. On the other hand, after a bad night, P3 amplitude was significantly higher among INS than among GS. In a similar design but this time using actigraphy for measuring sleep, the same group of researchers [39] observed larger P3 in INS on the worst night of sleep compared to GS. In 2009, Turcotte and Bastien investigated the relationship between PSG parameters and ERPs components in a multi-assessment protocol. These authors found that as the amplitude of N1 and P2 increased before going to sleep among INS, the sleep quality of the following night decreased. In addition, the sleep quality of the previous night also appeared to be linked to the ERPs' amplitudes recorded on the following morning. Turcotte and Bastien [40] concluded that the existing hyperarousal and inhibition deficits in INS are directly associated with a poorer sleep quality. Recently, Ceklic and Bastien [41] showed that of N1 and P2 behaviors, only N1 amplitude is linked to hyperarousal in both INS and GS while P2 amplitude was linked to sleep quality in both GS and INS. These results are methodologically important as they confirmed that both INS and GS cognitive processes are affected by sleep quality and that one night of neurophysiological recordings is not representative of true active cognitive processes. Furthermore, it might also suggest that increased arousal and inhibition deficits would be even greater in PARA-I since they always report a poor sleep quality compared to PSY-I and GS. This hypothesis is currently being tested by our team.

The utility of ERPs as a valuable tool to investigate information processing during wake and/or sleep in INS is unquestionable. We have objectively shown with our ERPs studies that PSY-I do differ from PARA-I, their cortical arousal being different. In addition, with ERPs, we were able to highlight that REM sleep might be the stage of sleep the more reflective or linked to sleep perception albeit misperception. ERPs provide a direct measure and precise timing of cortical arousal and dynamic neural mechanisms, contrary to PSA, which identifies the active brain structures at one moment in time.

7. Power spectral analysis (PSA)

PSA consists of Fast Fourier Transformations (FFT) revealing frequencies (measured in Hz) and amplitudes (measured in μV) of the waves constituting the different sleep stages. Averages of different frequency bands are calculated with bands usually defined as follow: slow wave (0–1 Hz), delta (1–4 Hz), theta (4–7 Hz), alpha (7–11 Hz), sigma (11–14 Hz), beta1 (14–20 Hz), beta2

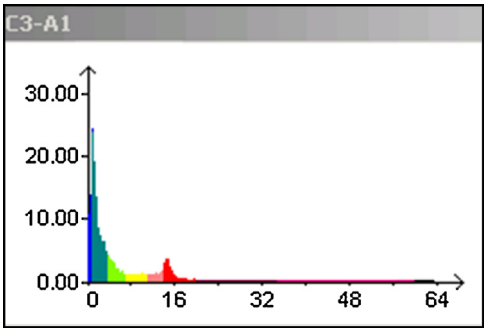

Fig. 3. Spectral graph. The spectral graph represents the result of power spectral analysis (PSA). EEG has been recorded at C3 (A1 being the reference) and PSA was performed on selected epochs of stage 2 sleep. Frequencies (Hz) are presented on the x-axis and power (μV^2) is found on the y-axis.

(20–35 Hz), gamma (35–60 Hz) and omega (60–125 Hz). Generally, rapid frequency bands (14–125 Hz) characterize elevated cortical activities whereas low frequency bands (1–14 Hz) suggest a reduced cortical activity. Data from PSA can be presented in two different ways: absolute power which is the power of one frequency band and/or relative power, which corresponds to the proportion of the power of one frequency band over the sum of power in all frequency bands. This technique allows the detection of finer alterations of sleep which would be impossible to identify using standard PSG (Fig. 3).

Up until now, PSA has been frequently used in INS research, and the results obtained tend to be in agreement, suggesting that INS' EEG is characterized by elevated activities in rapid frequency bands (in the sigma and beta range; for reviews see [13,42,43]). In fact, an increase in beta power was found during sleep-onset [44], stage 1 (S1) [45] and during non-REM sleep in general [46,47] in INS compared to GS. An increase in gamma activity [47] and a decrease in delta activity were found in INS during sleep in general as well [44]. More recently, a study failed to find significant differences in the frequency band activity between INS and GS during NREM sleep [48]. However, they showed that NREM sleep of female INS was characterized by increases in beta and delta powers. As for REM, the activity of the different frequency bands was found to differ across studies. While Freedman [45] showed elevated beta activity in INS, Perlis et al. [47] have observed that only beta2 activity was elevated during REM in INS. Finally, Merica and Gaillard [44] reported that INS had increased activities in alpha and sigma bands and decreased activities in delta and theta during REM. These results are difficult to reconcile. However, it is possible that contradictory results may be due to the fact that INS were not classified in different types and the possible existing cortical differences between PSY-I and PARA-I.

Thus far, only a few PSA studies have considered insomnia types and clustered their participants using their specific insomnia diagnoses. In the first PSA study, after 6 nights of PSG recording (3 at home and 3 in the sleep laboratory), relative and absolute powers of all frequency bands were shown to be similar for GS, PSY-I and PARA-I during REM sleep [12]. However, significant differences were found between groups during NREM sleep. PSY-I displayed significantly greater relative power in sigma activity compared to GS whereas PARA-I NREM sleep was characterized by lower delta and greater alpha, beta and sigma activities than GS [12]. Results for absolute power were similar except that there was no difference between groups in the delta band. These observations suggest that NREM sleep frequency activities are related to sleep complaints and misperception and might reflect the elevated level of hyperarousal during sleep found in PARA-I.

Recently, our group categorized PSY-I and PARA-I in two distinct groups and ran FFTs on two consecutive nights of PSG recordings [49]. Results showed higher absolute slow wave, delta, theta, alpha, sigma and gamma activities in PARA-I compared to PSY-I during NREM sleep. Relative power was also calculated and greater activities were found in slow wave, theta, alpha and sigma bands in PSY-I compared to PARA-I during REM sleep. In summary, the decrease in cortical activity during NREM sleep and the increased cortical activation in REM sleep shown in PARA-I might be linked to significant sleep misperception since this pattern of cortical activation was not observed in PSY-I.

Lastly, our group conducted a study to identify differences between insomnia types in hemispheric activation during sleep, which is termed cerebral asymmetry [11]. Frontal, central and parietal asymmetries in PSY-I, PARA-I and GS were documented on two consecutive nights in the laboratory. In the frontal regions, PARA-I displayed lower asymmetry in the omega band compared to GS; omega activity being dominant in the right hemisphere for GS while in the left one for PARA-I. Although both PSY-I and PARA-I presented higher beta activity in the right hemisphere than GS, a significantly higher asymmetry in the parietal regions was observed in the former group [11]. Finally, this study revealed that cerebral asymmetry varies from night-to-night, possibly reflecting the variability of sleep characteristic of INS. In summary, PSY-I and PARA-I have their own pattern of cerebral asymmetry, providing again empirical evidence for studying groups independently.

In brief, results obtained with PSA studies suggest that activities of the different frequency bands during NREM and REM sleep might contribute to sleep misperception characterizing PARA-I and the state of hyperarousal that is present during sleep in INS. Even though PSA studies categorizing INS in types are limited, these studies nonetheless suggest major differences between PSY-I and PARA-I. Therefore, to obtain representative data of respective sleep difficulties, it is mandatory that future PSA studies divide INS in types. Because both PSA and ERP results so far reveal important differences between PSY-I and PARA-I, other neurophysiological/microstructural measures, such as CAP, should also consider subdividing INS in types and could provide additional empirical data for a differential categorization between PSY-I and PARA-I.

8. Cyclic alternating patterns (CAPs)

The various stimuli, both internal and external, present during nighttime require sleepers to monitor them in order to adapt their vigilance consequently. This monitoring is possibly due to continuous fluctuations of the cortical activation levels. These fluctuations can be detected through phasic events which range from slow rhythms without macrostructural perturbation of sleep to fast rhythms that are associated with sleep fragmentation [50].

During NREM sleep, Terzano et al. [51] observed a periodicity of 20–40 seconds among phasic events. These authors witnessed that the distribution and organization of these periodic phasic events allowed the apparition of two different states: a phasic state which they named the CAP and a tonic state, the non-CAP (NCAP). Two different phases can be observed during CAP. 'A' phases are associated with higher cortical activation and periodic phasic events interrupting the tonic EEG activity which is itself associated with less activation and known as a 'B' phase [52,53]. 'A' phases can be further divided into three subtypes regarding their proportion of synchronious/desynchronious EEG and associated muscular tonus and neurovegetative responses. While subtype A1 mostly includes EEG synchronized patterns (K-Complexes and delta bursts) for at least 80% of their entire duration; subtype A2 includes from 80 to 50% of mixed synchronized–desynchronized EEG events in duration, and subtype A3 has less than 50% of their duration (predominantly desynchronized EEG events). Thus, of the

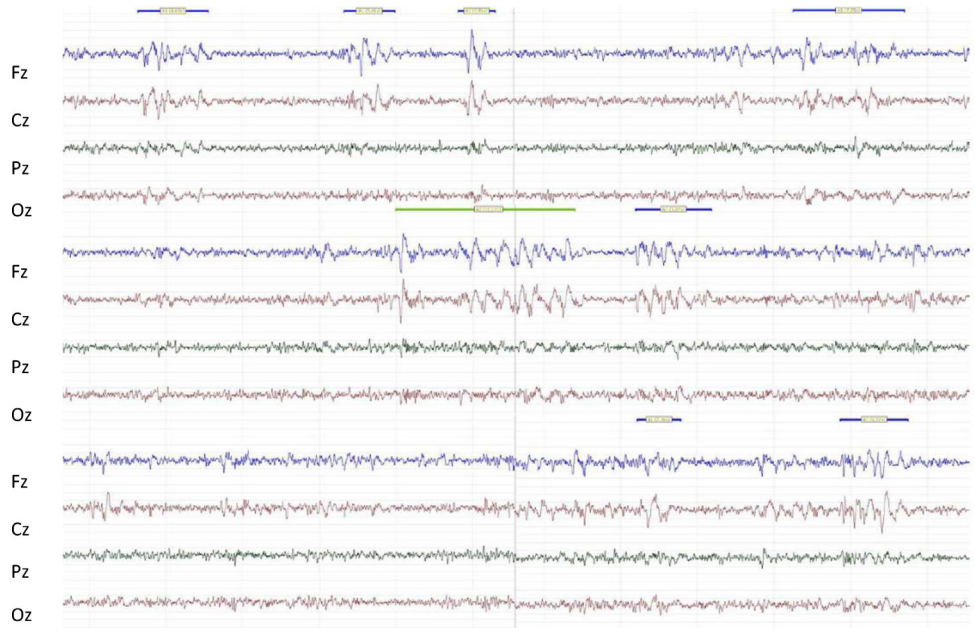

Fig. 4. Cyclic alternating pattern. This picture represents continuous EEG lasting 3 minutes divided in 3 sections of 60 seconds each. Signals (channels) recorded from the participant displayed in this figures are Fz, Cz, Pz and Oz. At the top of each section, events (A1 and A2 here) appear as defined in the CAP Atlas.
See Terzano MG, Parrino L, Smerieri A, Chervin R, Chokroverty S, Guilleminault C, et al. Atlas, rules, and recording techniques for the scoring of cyclic alternating pattern (CAP) in human sleep. *Sleep Med* 2001;2:537–53.

three subtypes, the A1 subtype represents the lowest level of activation whereas A3 represents the highest and A2 refers to an intermediate level [54]. Consecutive A and B phases form a CAP cycle, while two or more consecutive cycles form a sequence [52]. NCAP is a state of continuous EEG activity, during which phasic events are rare and isolated [53]. It is associated with stability of cortical excitability while CAP is associated with its instability [55,56] (Fig. 4).

Various CAP parameters can be computed, such as CAP time which is the added duration of the CAP sequences occurring during the night or the CAP rate which consists of the percentage of CAP time divided by the total NREM time [53]. These can be calculated for the whole night or specific sleep stages. CAP rate is the most used CAP parameter since it measures cortical activation instability and is associated with difficulties maintaining sleep [57].

In 1990, Terzano et al. conducted an acoustic perturbation study with a sample of healthy individuals. Their study revealed that not only does the level of acoustic perturbation lead to both microstructural and macrostructural alterations, it was also associated with their severity (or degree of alterations). The level of acoustic perturbation turned out to be positively associated with CAP rate which in turn correlated with both subjective and objective sleep quality. For example, while the higher CAP rate was mainly associated with less REM and slow wave sleep (SWS) at 45 dB, TST was not affected. On the other hand, at 65 dB, decreases in stage 4, REM and TST were observed with an increase in light sleep and wake after sleep-onset (WASO) [55]. Authors concluded that an association between sleep macro and microstructure is present: when sleepers are exposed to acoustic perturbation, their primary response is microstructural and CAP rate increases. However, once CAP rate reaches a certain level, and when instability overcomes stability, the microstructural disruption expands to macrostructure as well and lighter and more fragmented sleep can be observed. Therefore, microstructural flexibility allows the preservation of macrostructure [53,55].

A few studies focused on CAP measures in either INS or PSY-I only. CAP variables, and mostly CAP rate, showed to be the most efficient among various PSG measures for differentiating INS from GS, but also INS taking medication from those that did not [58–60]. These studies converge and show a higher CAP rate as well as more A phases among INS than GS [55,59,61]. However, group differences are attenuated by hypnotic medication [58–60,62] which is also associated with better sleep quality [62].

No study has yet compared PSY-I and PARA-I but one did specifically focus on PARA-I [63]. PARA-I showed a TST of at least 6.5 hours and a sleep-onset latency inferior to 30 minutes. In addition, a discrepancy of at least 120 minutes between objective and subjective TST and at least 20% between objective and subjective sleep latency was present. In regards of macrostructural data, PARA-I presented similar TST, NREM, REM and sleep latency relative to GS. A greater percentage in S1, S2 and awakenings, as well as less SWS was however observed in PARA-I. As for the microstructure, PARA-I presented a higher CAP rate during S1 and S2 but not during SWS. Furthermore, they had a higher percentage of A2 phases compared to GS. A higher CAP rate being associated with higher cortical activation and instability, it might have interfered with the deepening of sleep in PARA-I thus explaining the macrostructural differences.

Participants were asked to subjectively report their sleep-onset time (i.e. the time they thought they had fallen asleep). Reports were compared to the actual PSG-confirmed objective sleep-onset time. Very interestingly, for GS, sleep-onset time objectively corresponded to S2 sleep while it was S4 for PARA-I [63]. Moreover, during the interval between the subjective and objective sleep-onset time, PARA-I displayed higher CAP rate values than GS. A higher CAP rate during this period might have been perceived as wake by PARA-I. By being more activated cortically and therefore more able to monitor and process various stimuli, PARA-I might be more conscious and experience it as wake. A higher CAP rate might therefore explain the subjective-objective discrepancies observed in PARA-I. Parrino's study showed that microstructure might play a very important role in the misperception of sleep specific to PARA-I. More importantly, since usual PSG measures are similar between GS and PARA-I, it leads to the hypothesis that the macrostructural preservation among PARA-I might be explained by a perturbation

of the micro-/macrostructural association. If PARA-I present an alteration of the micro-/macroassociation, their microstructure might be too flexible allowing an increase in cortical activation without any alteration to the macrostructure. This increase would then have an impact on their subjective perception making them more vulnerable to stimuli by being more conscious and therefore aware, leading them to think they are awake during PSG verified sleep. It is also possible the heightened sensation of being awake is not linked to an increased flexibility in the macro-/microstructure but instead, be explained by a diminished ability of the EEG to protect the sleeping brain. As we know, phasic transient events are also expressed through K-Complexes and sleep spindles, both these phenomena being increasingly associated with sleep protection.

9. K-Complex

The K-Complex (KC) can occur spontaneously (spontaneous KC–SKC) or be evoked by a stimulus (evoked KC–EKC) [64,65]. The EKC and SKC are virtually identical and seem to be induced by both external and internal stimulation [66–68]. This transient and phasic phenomenon is characteristic of NREM sleep and occurs every two to three minutes, though the frequency of occurrence varies greatly both within and between normal sleepers. In line with the definition of Rechtschaffen and Kales [69], the KC is generally considered as a negative sharp wave (N550) followed by a positive component (P900). Its duration is longer than 0.5 second. In addition, to distinguish the KC from other delta waves which are particularly present during SWS, minimal amplitude of 75 μV is generally required. The definition of the EKC is similar to the one of SKC [70].

Halász [71] and Colrain [72] reported, in their respective reviews, that the association observed between KCs and autonomous and muscle activation has led some authors to consider the KC as a sign of arousal. However, more recent studies rather yield evidence toward a sleep-protective role. For example, an increase in activity in fast frequencies bands was observed following the presentation of a stimulus in the absence of a KC during SWS while, when a KC was evoked, the EEG remained unchanged post-stimulus [73,74]. Furthermore, fragmentation and sleep deprivation have been shown to be associated with enhanced production of KCs during recovery nights [75,76]. A higher prevalence of KCs was also observed during S2 preceding SWS when compared to S2 preceding REM sleep, suggesting the KC might be associated with delta waves especially since a linear increase in KCs occurs before the transition to SWS [77].

In recent years, the idea of the KC being both an arousal and sleep-protective mechanism, has gained popularity. In 1993, Halász [78] suggested the existence of a microstate allowing enhanced receptivity to stimulation while preserving sleep as much as possible. More recently, Amzica's work revealed that sequences of hyperpolarization and depolarization of the membrane potential among cortical neurons result in a slow oscillation (< 1 Hz) which would be the origin of a majority of KC appearing in the sleeping brain. The periodic occurrence of SKCs usually emerges from this slow oscillation, although some SKCs may also appear in isolated and arrhythmic forms. During light sleep, the slow oscillation is less organized and synchronized and therefore the occurrence of KCs is less systematic. However, with the deepening of sleep, as the oscillation becomes faster and more regular, KCs become more rhythmic [79,80]. The periodic recurrence of the KC might be a swaying between a state of readiness of the cortical network to operate in the event of a danger (depolarization or up-state) and a condition for brain rest (hyperpolarization or down-state) [80]. In regard to this latter hypothesis, Cash et al. [81] have shown that the N550 component of the KC is a cortical down-state, therefore supporting the idea that at least some part of the KC decreases cortical activity shown in response to stimulation processed as irrelevant. It should be noted that for Cash et al. [81], the KC is not considered only as a slow oscillation since it can be evoked by stimulation. Recent fMRI/EEG studies concluded the KC is preceded by a state during which the brain's receptivity to stimulation is temporarily enhanced allowing for enhanced information processing. Then, the KC counter-reacts in order to protect sleep [82,83].

Unfortunately, KC's role and characteristics have been poorly documented among INS, despite the fact that protective sleep mechanisms appear as an area of interest for this population. When documented, results are often contradictory. Wauquier et al. [84] compared the occurrence of SKCs during S2 among patients suffering from various sleep disorders (including insomnia without any comorbities) and GS. These authors observed a lower occurrence among the former group, INS. They concluded that the presence of an altered sleep-protective mechanism was active in INS. On the other hand, Bastien et al. [85] observed no significant difference between PSY-I and GS on both number and density of SKCs in S2. While studying the EKC this time, Hairston et al. [86] observed an increase in KC associated with stimulation for GS but not for INS. In contrast, Forget et al. [74] did not find any differences in number and density in EKC between INS and GS. Thus, so far, the role of the KC, albeit spontaneous or evoked, is unresolved. Moreover, since few studies have been conducted on the KC in INS, to this day, the role of the KC in sleep misperception remains unknown. However and as mentioned earlier, PARA-I appear to present more difficulties inhibiting information processing during sleep than PSY-I [35]. It is possible that the KC has a diminished capacity for decreasing cortical activity linked to irrelevant stimulation. This hypothesis also remains to be tested.

10. Spindles

Sleep spindles consist of an EEG burst, oscillating between 11 and 15 cycles per second (Hz) and lasting at least half a second. Even though they occur during S2 and SWS, they are hallmarks of S2 sleep [87]. Their apparition in the EEG indicates that the person has fallen asleep [69]. Sleep spindles are considered to play a role as sleep-protective mechanisms [69,87,88] and are implicated in sensorial treatment inhibition, specifically disengagement of disturbing and/or intrusive stimuli [89–93]. Factors known to affect sleep spindles are variation effect of delta wave activity, effects of sleep deprivation, time over night, intra-cycle temporal dynamics, circadian factors, hypnotic intake and ageing [87].

The mechanism of spindle generation is seen as a combination of intrinsic properties and interaction between the thalamic reticular nucleus and the thalamocortical pathway [94,95]. In short, the GABAergic neurons of the reticular nucleus of the thalamus, through repetitive inhibitory bursts, cause inhibitive postsynaptic potentials in the thalamocortical relay neurons. In other words, the bursts decrease the neural activity of the path between thalamus and cortical neurons. This thalamocortical inhibition has a great influence on the cortical neurons, resulting in disconnection of the cortex from the external environment. Moreover, since the thalamic reticular neurons act as pacemakers for thalamocortical bursting activity, it supports the gating role of sleep spindles in sensory information processing [87].

While simultaneously recording EEG and functional MRI (fMRI), Caporro et al. [96] found that principal brain regions activated during the occurrence of sleep spindles are primarily the bilateral thalami, paracentral regions, and temporal lobes. These brain regions correspond to the limbic system and paralimbic activity,

both being important in memory consolidation. Therefore, sleep spindles would be associated with the consolidation of knowledge by the integration of new information [97]. Otherwise, it suggests that sleep spindles are involved in sleep-maintenance because the same brain regions are essential parts of the processing of external sensory stimuli. While various kinds of spindles exist, they are generally divided in two types according to their frequency and cortical distribution; slow spindles (from 11 to 13 Hz) are more abundant in the frontal lobe and fast spindles (from 13 to 15 Hz) are mainly found in the centro-parietal regions [87,98–100].

Just as the KC, spindles are an area of interest for INS since they allow us to investigate the preservation of sleep-protective mechanisms within this population. Sleep spindles facilitate the emergence of slow waves by allowing the inhibition of cortical activation. However, compared to GS, INS are known to be cortically hyperaroused during sleep [28] and this could interfere with spindle generation. Surprisingly, results have shown that the occurrence of sleep spindles is similar among PSY-I and GS [101]. In other words, sleep-protective mechanisms seemed intact in PSY-I. Furthermore, since PARA-I present cortical activation pattern even more pronounced than PSY-I [12,102], our group [103] has compared the occurrence of sleep spindles in both type of INS (PARA-I and PSY-I) at the frontal site which is usually associated with cortical deactivation. Again, results have shown no difference between PARA-I and PSY-I, suggesting that the microstructure of S2 in INS does not show sleep protection deficits. Unfortunately, the role of the sleep spindle related to misperception has not been investigated but similar hypotheses than the ones posited for the KC can be set forward in the context of the sleep spindle.

11. Conclusion

Although many studies on insomnia have been conducted so far, only a paucity of them directly addresses the question of sleep perception, or misperception. This is rather peculiar as the clinical feature of this disorder is mainly based on the subjective report of sleep difficulties, which are themselves not adequately confirmed by sleep research gold standard, polysomnography. In this paper, we have reviewed the empirical evidence of the presence of neurophysiological characteristics, especially with PSA and ERPs, for each type of insomnia sufferers, psychophysiological and paradoxical ones. Even if this evidence appears scarce, it is nonetheless important and even vital as it might have significant repercussions on the subjective evaluation of sleep. Future studies shall thus keep on exploring the hyperarousal concept related to misperception as well as sleep quality (subjective and objective) and its consequences on neurophysiological endpoints in insomnia research. Furthermore, more information and a better understanding of the different clinical and even polysomnographic correlates of sleep misperception is desperately needed to aid the sleep medicine specialist better design treatment plans for suffering patients, especially those grossly misestimating their sleep.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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Appendix A. Consensus Sleep Diary

Carney CE, Buysse DJ, Ancoli-Israel S, Edinger JD, Krystal AD, Lichstein KL, et al. The consensus sleep diary: standardizing prospective sleep self-monitoring. *Sleep* 2012;35(2):287–302.

Permission to use the Consensus Sleep Diary is restricted to clinical use only. Permission to use it in research shall be addressed to ccarney@ryerson.ca.

Sample ID/Name: _____

Today's date	4/5/11							
1. What time did you get into bed?	10:15 p.m.							
2. What time did you try to go to sleep?	11:30 p.m.							
3. How long did it take you to fall asleep?	55 min.							
4. How many times did you wake up, not counting your final awakening?	3 times							
5. In total, how long did these awakenings last?	1 hour 10 min.							
6. What time was your final awakening?	6:35 a.m.							
7. What time did you get out of bed for the day?	7:20 a.m.							
8. How would you rate the quality of your sleep?	❑ Very poor ❑ Poor ❑ Fair ❑ Good ❑ Very good	❑ Very poor ❑ Poor ❑ Fair ❑ Good ❑ Very good	❑ Very poor ❑ Poor ❑ Fair ❑ Good ❑ Very good	❑ Very poor ❑ Poor ❑ Fair ❑ Good ❑ Very good	❑ Very poor ❑ Poor ❑ Fair ❑ Good ❑ Very good	❑ Very poor ❑ Poor ❑ Fair ❑ Good ❑ Very good	❑ Very poor ❑ Poor ❑ Fair ❑ Good ❑ Very good	❑ Very poor ❑ Poor ❑ Fair ❑ Good ❑ Very good
9. Comments (if applicable)	I have a cold							

Consensus Sleep Diary © 2011

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